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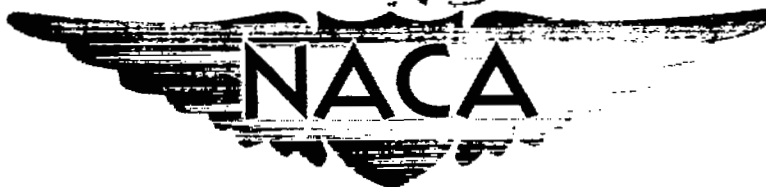
NACA

RESEARCH MEMORANDUM

A WIND-TUNNEL INVESTIGATION AT LOW SPEEDS OF THE

AERODYNAMIC CHARACTERISTICS OF VARIOUS

SPOILER CONFIGURATIONS ON A

THIN 60° DELTA WING

By Harleth G. Wiley and Martin Solomon

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Langley Field, Va.

FOR REFERENCE

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NATIONAL ADVISORY COMMITTEE
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RESEARCH MEMORANDUM

A WIND-TUNNEL INVESTIGATION AT LOW SPEEDS OF THE

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SUMMARY

A preliminary investigation has been made in the Langley 300 MPH 7- by 10-foot tunnel to determine the applicability of spoilers as lateral-control devices on thin delta wings. The wing used was a flat steel plate of constant thickness with beveled leading and trailing edges and had a thickness ratio of 1.5 percent at the root and a maximum ratio of 4.5 percent at 66.7 percent wing semispan. The wing had 60° sweepback at the leading edge, 0° sweep of the trailing edge, an aspect ratio of 2.31, and a taper ratio of 0. Lateral-control characteristics were obtained for the model with one wing semispan equipped with various types of spoilers. Briefly investigated also were the effects of spoiler perforations and wing slots on spoiler performance.

The data indicated that adequate rolling moment throughout the usable lift range can be obtained with a spoiler extending from the fuselage to 67- to 75-percent semispan and with the spoiler located behind the 75- to 80-percent wing-root-chord station. Rolling moment increased linearly with increase in spoiler projection at all angles of attack and spoiler projections investigated up to a spoiler projection of -8.7-percent mean aerodynamic chord.

INTRODUCTION

Wider usage of thin delta wings for high-speed airplanes has introduced the problem of providing adequate lateral control throughout the usable lift range. From past experience on straight and swept wings (refs. 1 and 2), the spoiler appears to offer several distinct advantages over traditional lateral-control devices. The use of spoilers offers the possibilities of adequate lateral control with predictable and low

hinge moments, of maximum reduction in wing twist with consequent decreased problems of control reversal, and of minimum structural interference with high-lift and longitudinal control devices.

As part of an over-all program to determine a satisfactory lateral control for thin delta wings, the National Advisory Committee for Aeronautics investigated in the Langley 300 MPH 7- by 10-foot tunnel the applicability of spoiler-type, lateral-control devices to thin delta wings.

Reported herein are the results of exploratory tests at low speeds of various locations and configurations of spoilers on a 60° delta wing. The wing used was essentially a flat steel plate of constant thickness with beveled leading and trailing edges. The thickness ratio varied from approximately 1.5 percent at the root to a maximum of 4.5 percent at 66.7-percent wing semispan. The wing had a leading-edge sweepback of 60°, a trailing-edge sweep of 0°, an aspect ratio of 2.31, and a taper ratio of 0. Most of the tests were made through an angle-of-attack range from -4° to 36° with some tests made from -10° to 33°. The Reynolds number, based on the mean aerodynamic chord, was 3×10^6.

COEFFICIENTS AND SYMBOLS

The results of the tests are presented as standard NACA coefficients of forces and moments about the stability axes as shown in figure 1. The coefficients and symbols used herein are defined as follows:

C_L lift coefficient, Lift/qS

C_D drag coefficient, Drag/qS

C_m pitching-moment coefficient referred to $0.25\bar{c}$, Pitching moment/$qS\bar{c}$

C_l rolling-moment coefficient due to spoiler projection, Rolling moment of spoiler and wing less rolling moment of wing alone/qSb

C_n yawing-moment coefficient due to spoiler projection, Yawing moment of spoiler and wing less yawing moment of wing alone/qSb

q free-stream dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft

S wing area, 6.93 sq ft

$\bar{c}$ mean aerodynamic chord of wing, $\dfrac{2}{S}\displaystyle\int_0^{b/2} c^2\,dy$, 2.31 ft

c_r root chord of wing, 3.46 ft

c_t tip chord of wing, 0 ft

c   local wing chord, ft

b   span of wing, 4.00 ft

y   spanwise distance from plane of symmetry, ft

V   free-stream air velocity, ft/sec

ρ mass density of air, slugs/cu ft

R   Reynolds number of wing based on $\bar{c}$

α angle of attack of wing, deg

δ_s spoiler projection, percent $\bar{c}$, negative when projected above the upper surface of the wing

MODEL AND APPARATUS

The wing had a leading-edge sweepback of 60°, a trailing-edge sweep of 0°, an aspect ratio of 2.31, a taper ratio of 0, and was constructed of a $\frac{5}{8}$-inch-thick flat steel plate with beveled leading and trailing edges (fig. 2). The resulting airfoil varied in thickness ratio from about 1.5-percent chord at the wing root to a maximum ratio of 4.5 percent at station 0.667b/2, tapering with constant 4.5-percent-thickness ratio to zero chord at the wing tip.

Dimensions and locations of the various spoiler configurations, hereinafter referred to as spoilers 1 to 14, are given in figure 3. Plain spoilers, 1 to 11, and 13 and 14, were made of aluminum angle brackets attached to the upper surface of the wing and had a projection δ_s of $-0.072\bar{c}$. Wedge spoiler 12 with projections of $-0.010\bar{c}$, $-0.025\bar{c}$, $-0.035\bar{c}$, $-0.050\bar{c}$, and $-0.087\bar{c}$ at its maximum height was made of wood. Spoiler 13 consisted of a plain spoiler with a $0.03\bar{c}$ wide slot in the wing immediately behind the spoiler. The slot extended from the fuselage to 0.67b/2 with the slot leading edge coinciding with the spoiler trailing edge. Perforated spoiler-slot configuration 14 was obtained by modifying spoiler-slot

configuration 13 with a series of 0.25-inch-diameter holes, removing approximately 40 percent of the total spoiler projected area.

The model was tested on the single support strut of the Langley 300 MPH 7- by 10-foot tunnel and was attached to the tunnel balance system for measurement of aerodynamic forces and moments. A small fairing or fuselage was used on the model to cover the support-strut linkages.

TEST CONDITIONS AND CORRECTIONS

The tests were made in the Langley 300 MPH 7- by 10-foot tunnel at a dynamic pressure q of 56 pounds per square foot, corresponding to a Mach number of about 0.195. Reynolds number for the tests, based on the mean aerodyanmic chord of the model, was about 3×10^6. The tests were made at an angle of sideslip of 0^0 and through an angle-of-attack range from -4^0 to 36^0 for most of the tests with one configuration tested from -10^0 to 33^0.

The jet-boundary corrections applied to the data of this paper were obtained by the method outlined in reference 3. Jet-boundary corrections applied are as follows:

$$\Delta C_L = 0.638 C_L$$

$$\Delta C_D = 0.011 C_L^2$$

Corrections for tunnel blockage and buoyancy are negligible and were, therefore, not applied to these data.

RESULTS AND DISCUSSION

The aerodynamic characteristics of a plain 60^0 delta wing are given in figure 4.

Effect of Spoiler Location and Angular Placement

Examination of the lateral characteristics of plain spoilers 1 to 9 in figures 5 and 6 reveals that the maximum and most constant rolling-moment coefficient throughout the usable lift range was obtained for plain spoiler 4, located at $0.87 c_r$ and extending from the fuselage to $0.75 b/2$. All other plain spoiler configurations of figures 5 and 6,

regardless of location or angular placement on the wing surface, did not produce adequate or sufficiently constant rolling moment throughout the lift range. Since spoiler 3, located at the 70-percent root-chord station, was ineffective in producing rolling moment at low angles of attack, it appears that, in order to maintain roll effectiveness throughout the usable lift range on a thin delta wing, a spoiler must be located near the wing trailing edge, probably behind the 75- to 80-percent root-chord station.

Yawing-moment coefficients for spoiler configuration 4 were favorable at angles of attack less than approximately 11° and adverse above $\alpha = 11^{\circ}$.

Effect of Spanwise Location

The incremental contributions of the inboard and outboard halves of spoiler 4, tested separately as spoilers 10 and 11, respectively, are presented in figure 7. At angles of attack up to about 28°, rolling-moment coefficient produced by inboard spoiler 10 generally increases with increase in angle of attack. Outboard spoiler 11 contributes approximately 60 percent of the rolling moment produced by the full-length spoiler 4 throughout the usable lift range, the rolling moment produced increasing slightly up to an angle of attack of 12° and decreasing slightly above $\alpha = 12^{\circ}$. (The increase in total rolling moment produced by the two half sections over that obtained with the complete spoiler (fig. 7) probably results from the increase in affected wing area caused by the diverging wake at each half-spoiler tip.) From the data it is apparent that, at angles of attack less than 12°, the outboard spoiler produces the greater increment of rolling moment, whereas above $\alpha = 12^{\circ}$, the inboard spoiler is more effective in producing rolling moment. More comprehensive data are needed to determine the optimum spoiler span and spanwise position.

Effect of Spoiler Projection

The variations of rolling- and yawing-moment coefficients with angle of attack for spoiler 12, located in the region of good spoiler effectiveness at $0.90c_r$, for projections of $-0.010\bar{c}$, $-0.025\bar{c}$, $-0.035\bar{c}$, $-0.050\bar{c}$, and $-0.087\bar{c}$ are presented in figure 8. The variations of rolling-moment and yawing-moment coefficients with spoiler projection at constant angles of attack for spoiler 12 are presented in figure 9. For a spoiler extending from the fuselage to $0.67b/2$, the increase in rolling moment with increase in projection is linear over the usable lift range. In general, the yawing-moment coefficients for low angles of attack were favorable but became unfavorable at higher angles of attack for all spoiler projections.

Effect of Slots and Perforations

Presented in figure 10, and compared with the results of spoiler 4, are the lateral-control characteristics of spoilers 13 and 14, a spoiler mounted at the 85-percent root-chord station and extending from the fuselage to 0.75b/2 with a slot located immediately behind the spoiler. (The 0.02c difference in chordwise location between spoilers 4 and 13 is not believed appreciable for comparison of spoiler effectiveness.) Addition of the slot caused an increase in rolling power of approximately 10 percent at angles of attack from 12° to 28°, resulting in a nearly constant rolling-moment coefficient throughout the range of angle of attack. This trend is also shown in reference 4 for a slotted spoiler on a 60° sweptback wing. Since the effectiveness of a slot is dependent upon both the shape and size of the slot, the present investigation, preliminary in nature, is indicative only of the beneficial effect of the slot.

Figure 10 reveals that perforations in the spoiler decreased the rolling moment obtainable approximately 40 percent at $\alpha = 0°$ and 10 percent at $\alpha = 28°$. (This trend was also exhibited by a perforated spoiler on a 32.6° sweptback wing as reported in ref. 5.)

CONCLUSIONS

From results of an exploratory investigation at low speeds of various locations and configurations of spoilers on a thin 60° delta wing, the following conclusions may be made:

1. Adequate rolling moment throughout the usable lift range may be obtained with a spoiler located near the wing trailing edge (behind the 75- to 80-percent root-chord station). Yawing moments were favorable at angles of attack less than approximately 11° and adverse above 11°.

2. The greatest increment of rolling moment produced by a spoiler located at the 87-percent root-chord station was contributed by the outboard half-section at angles of attack less than 12° and by the inboard half-section at the higher angles of attack. More comprehensive data are needed to determine optimum spoiler span.

3. For a spoiler located at the 90-percent root-chord station and extending from the fuselage to 66.7 percent wing semispan the rolling-moment coefficient produced increased linearly with increase in spoiler projection at all angles of attack up to a spoiler projection of -8.7-percent mean aerodynamic chord, the maximum projection investigated.

4. A slot, with a width of 3-percent mean aerodynamic chord, and located immediately behind a spoiler at the 85-percent root-chord station, appreciably increased the rolling-moment coefficient produced at the higher angles of attack, resulting in a nearly constant rolling-moment coefficient throughout the usable lift range.

5. A perforated spoiler located at 85-percent root chord was less effective in producing rolling moments than was a solid spoiler.

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      National Advisory Committee for Aeronautics,
            Langley Field, Va.

REFERENCES

1. Fischel, Jack, and Ivey, Margaret F.: Collection of Test Data for Lateral Control With Full-Span Flaps. NACA TN 1404, 1948.

2. Rogallo, Francis M., Lowry, John G., and Fischel, Jack: Lateral-Control Devices Suitable for Use With Full-Span Flaps. Jour. Aero. Sci., vol. 17, no 10, Oct. 1950.

3. Gillis, Clarence L., Polhamus, Edward C., and Gray, Joseph L., Jr.: Charts for Determining Jet-Boundary Corrections for Complete Models in 7- by 10-Foot Closed Rectangular Wing Tunnels. NACA ARR L5G31, 1945.

4. Hammond, Alexander D., and Watson, James M.: Lateral-Control Investigation at Transonic Speeds of Retractable Spoiler and Plug-Type Spoiler-Slot Ailerons on a Tapered 60° Sweptback Wing of Aspect Ratio 2. Transonic-Bump Method. NACA RM L52F16, 1952.

5. Vogler, Raymond D.: Wind-Tunnel Investigation at High Subsonic Speeds of Spoilers of Large Projection on an NACA 65A006 Wing With Quarter-Chord Line Swept Back 32.6°. NACA RM L51L10, 1952.

Lift

Z

α

X

Yawing moment

Side force

Y

Wind

Pitching moment

Y

Rolling moment

X   Drag

Z

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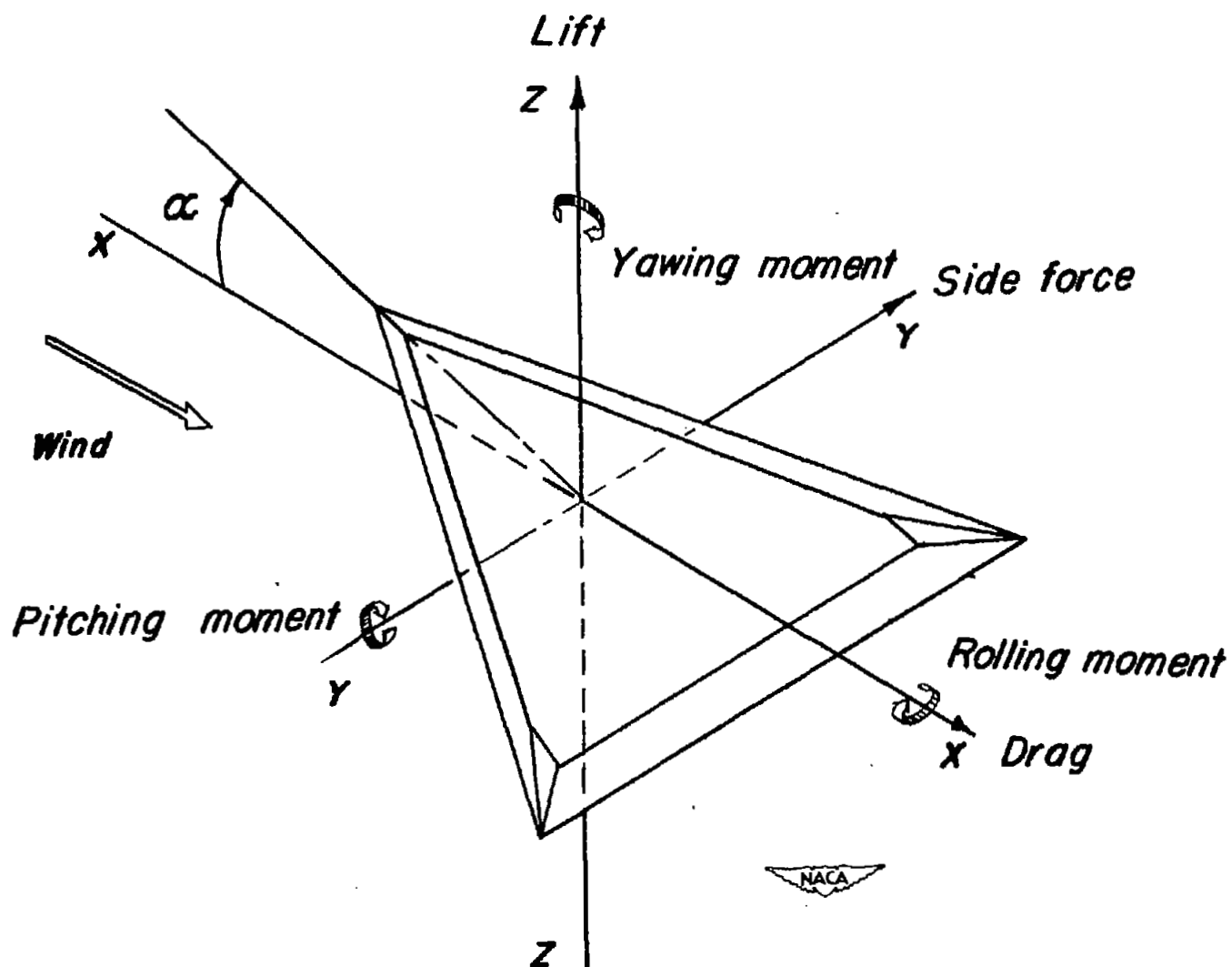
Figure 1.- System of stability axes. Positive values of forces, moments, and angles are indicated by arrows.

5.30

.25 c̄

15.98

24.00

48.00

5.0

4.0

60°

2.5

5/8

c̄ = 27.71

20

4.39

Centerline
of balance

41.57

800

6.8°

8.2°

Aspect ratio, $\frac{b^2}{S}$ 2.31

Taper ratio, $\frac{c_t}{c_r}$ 0

Area   6.93ft²

Thickness ratio, $\frac{t}{c}$

Root   0.015
Maximum   0.045

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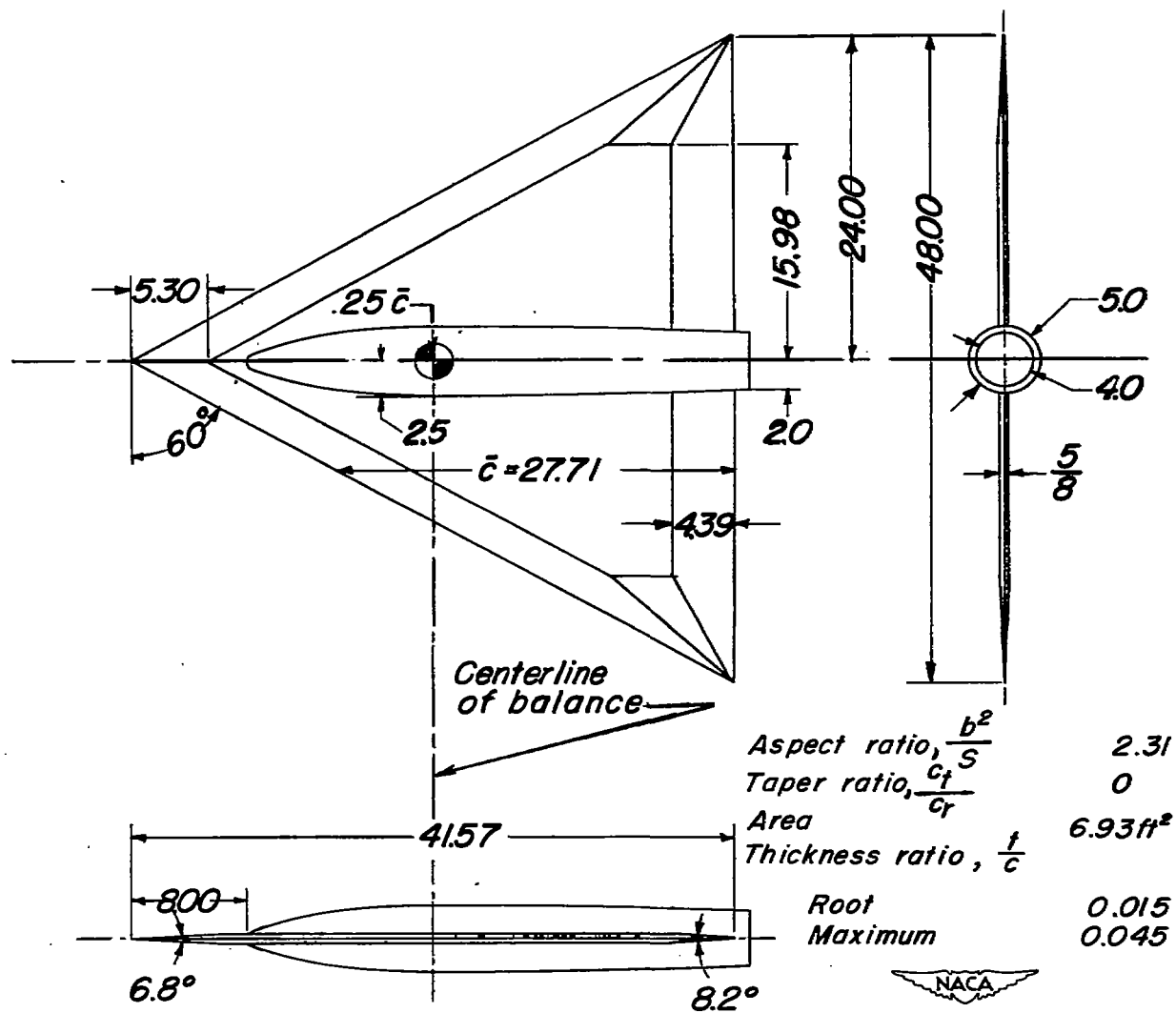
Figure 2.- Sketch of plain, thin 60° delta wing as tested. All dimensions
are in inches unless otherwise noted.
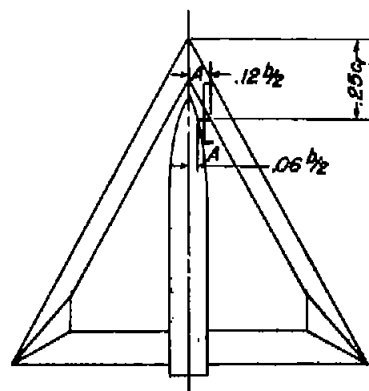
(a) Spoiler 1. $\delta_s = -0.072\bar{c}$.

(b) Spoiler 2. $\delta_s = -0.072\bar{c}$.

0.072$\bar{c}$

Section A-A
(Typical section of
spoilers 1,2,3,and 4)
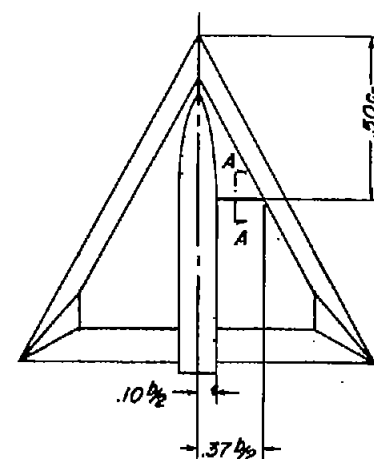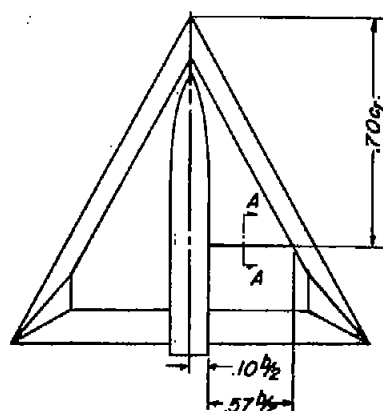
(c) Spoiler 3. $\delta_s = -0.072\bar{c}$.
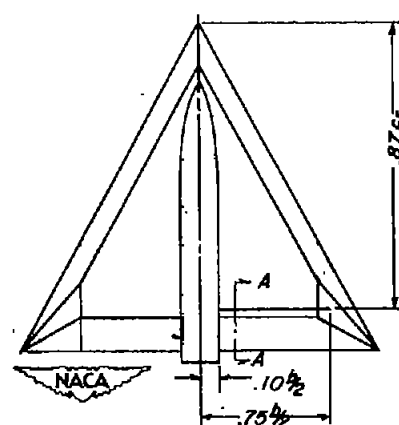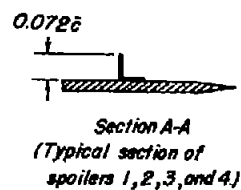
(d) Spoiler 4. $\delta_s = -0.072\bar{c}$.

Figure 3.- Various spoiler configurations tested on 60° thin delta wing.
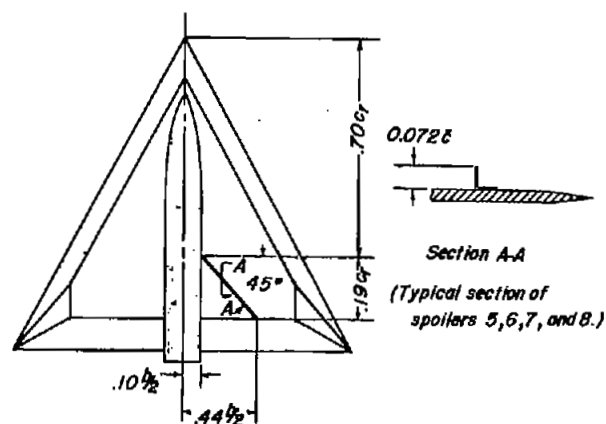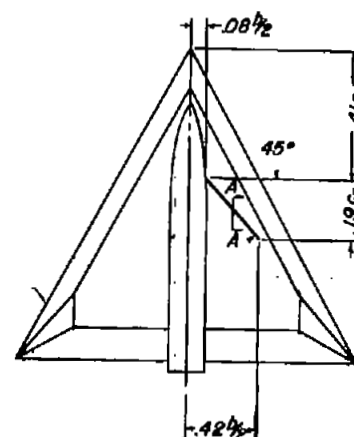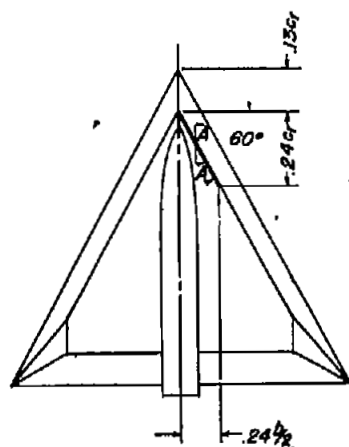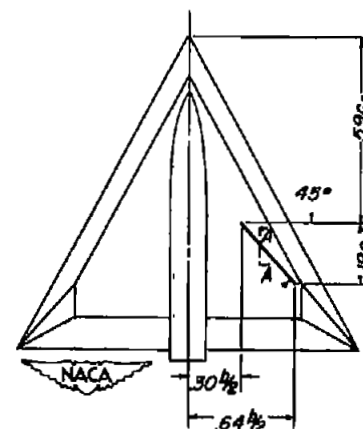
0.072c

Section A-A

(Typical section of
spoilers 5,6,7, and 8.)

(e) Spoiler 5. $\delta_s = -0.072\bar{c}$.

(f) Spoiler 6. $\delta_s = -0.072\bar{c}$.

(g) Spoiler 7. $\delta_s = -0.072\bar{c}$.

(h) Spoiler 8. $\delta_s = -0.072\bar{c}$.

Figure 3.- Continued.

0.072$\bar{c}$

Section A-A

(Typical section of spoilers 9, 10, and 11)

(i)   Spoiler 9. $\delta_s = -0.072\bar{c}$.

(j)   Spoiler 10. $\delta_s = -0.072\bar{c}$.

$\delta_s = -0.015\bar{c}$
$\delta_s = -0.025\bar{c}$
$\delta_s = -0.035\bar{c}$
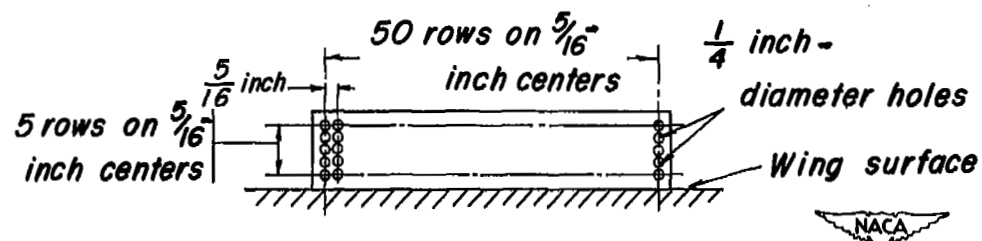$\delta_s = -0.050\bar{c}$
$\delta_s = -0.087\bar{c}$

δ_s

Sta. 0.90c_r
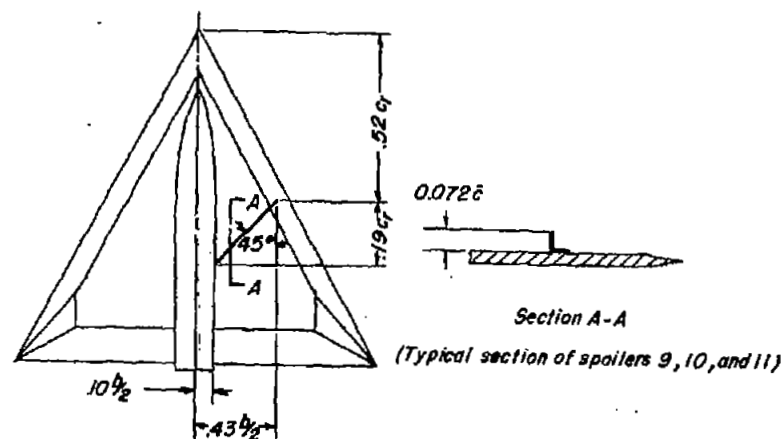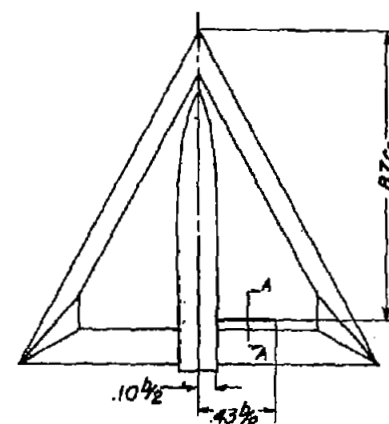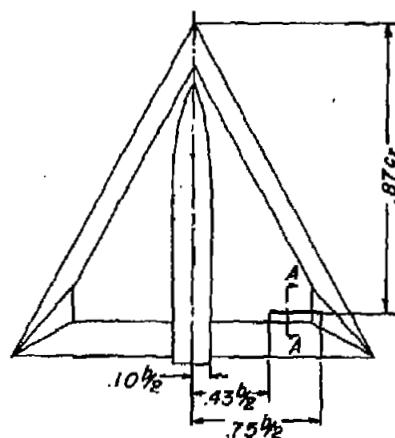
Section B-B
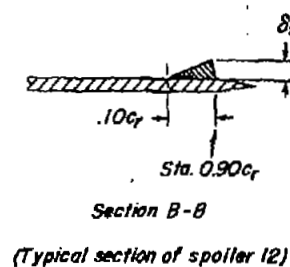
(Typical section of spoiler 12)
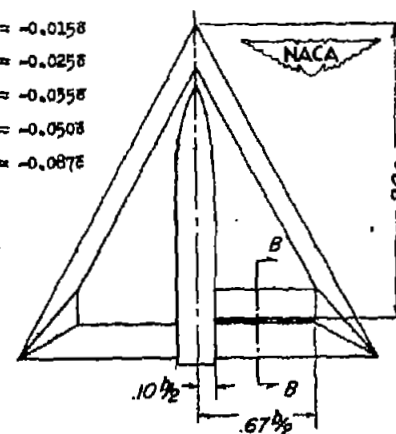
(k)   Spoiler 11. $\delta_s = -0.072\bar{c}$.

(l)   Spoiler 12.

Figure 3.- Continued.

Station .85 c_r

.03$\bar{c}$ slot
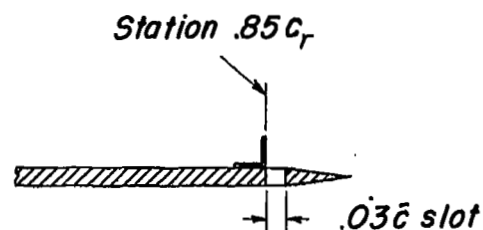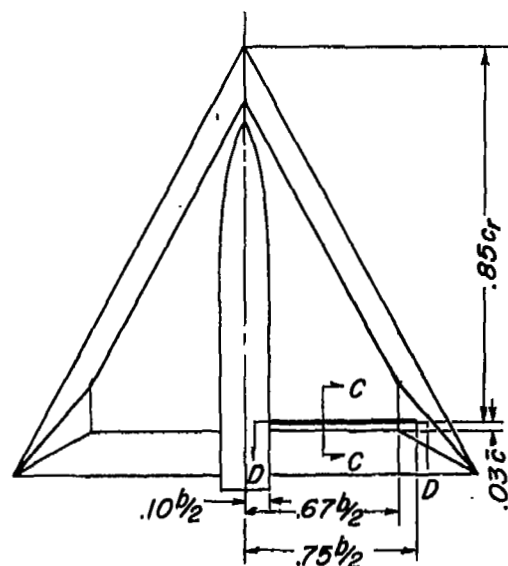
Section C-C (Typical section of slot behind spoilers 13 and 14.)

50 rows on $\frac{5}{16}$-inch centers

$\frac{1}{4}$ inch-diameter holes

$\frac{5}{16}$ inch

5 rows on $\frac{5}{16}$-inch centers

Wing surface

.85c_r

.03$\bar{c}$

.10$\frac{b}{2}$ .67$\frac{b}{2}$

.75$\frac{b}{2}$

Section D-D (Hole spacing in perforated spoiler 14.)

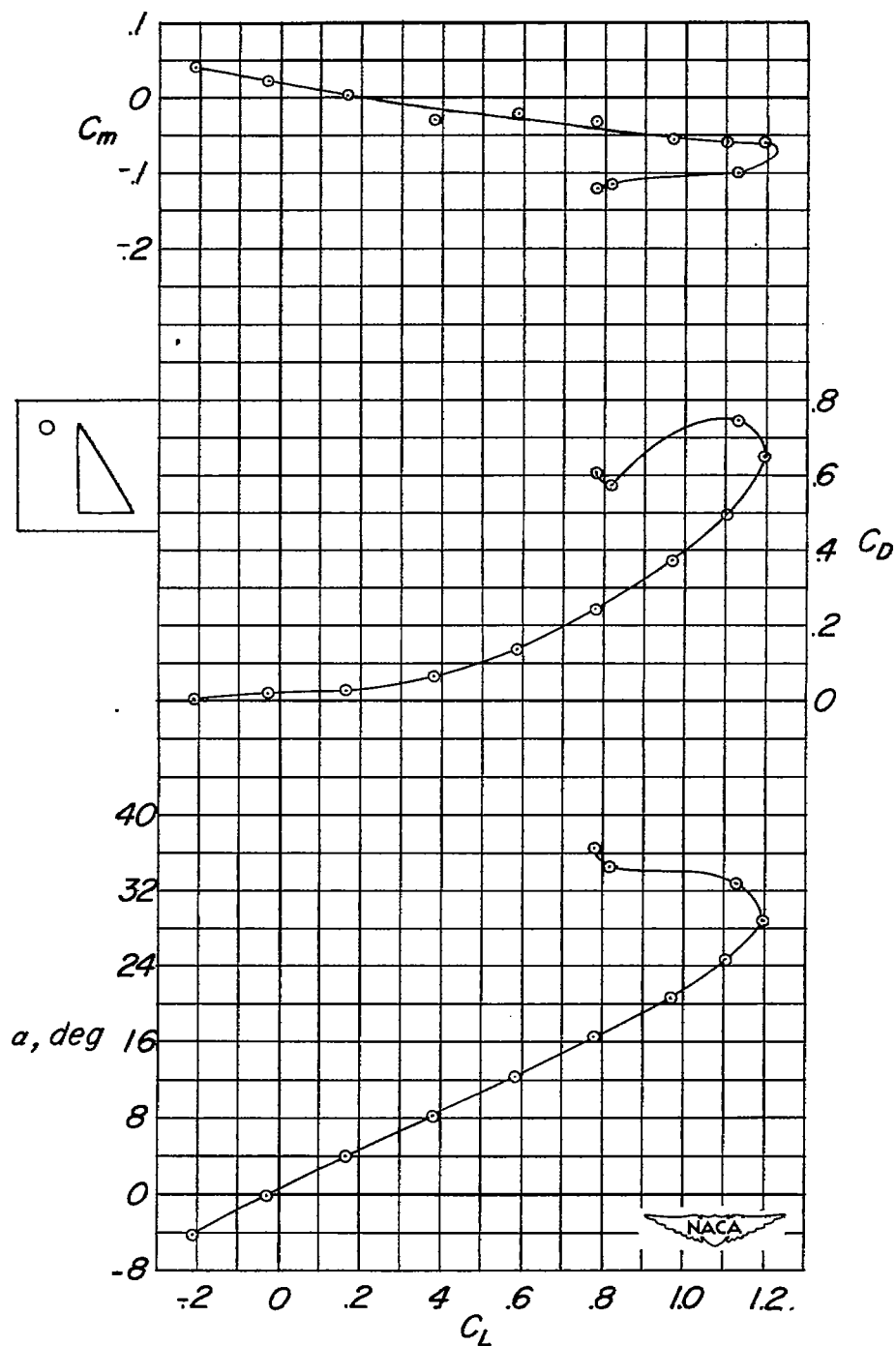(m)   Spoilers 13 and 14, unperforated and perforated, respectively. $\delta_s = -0.072\bar{c}$.

Figure 3.- Concluded.

Figure 4.- The aerodynamic characteristics of a plain 60° delta wing with aspect ratio of 2.31, taper ratio of 0, and constant thickness airfoil section.
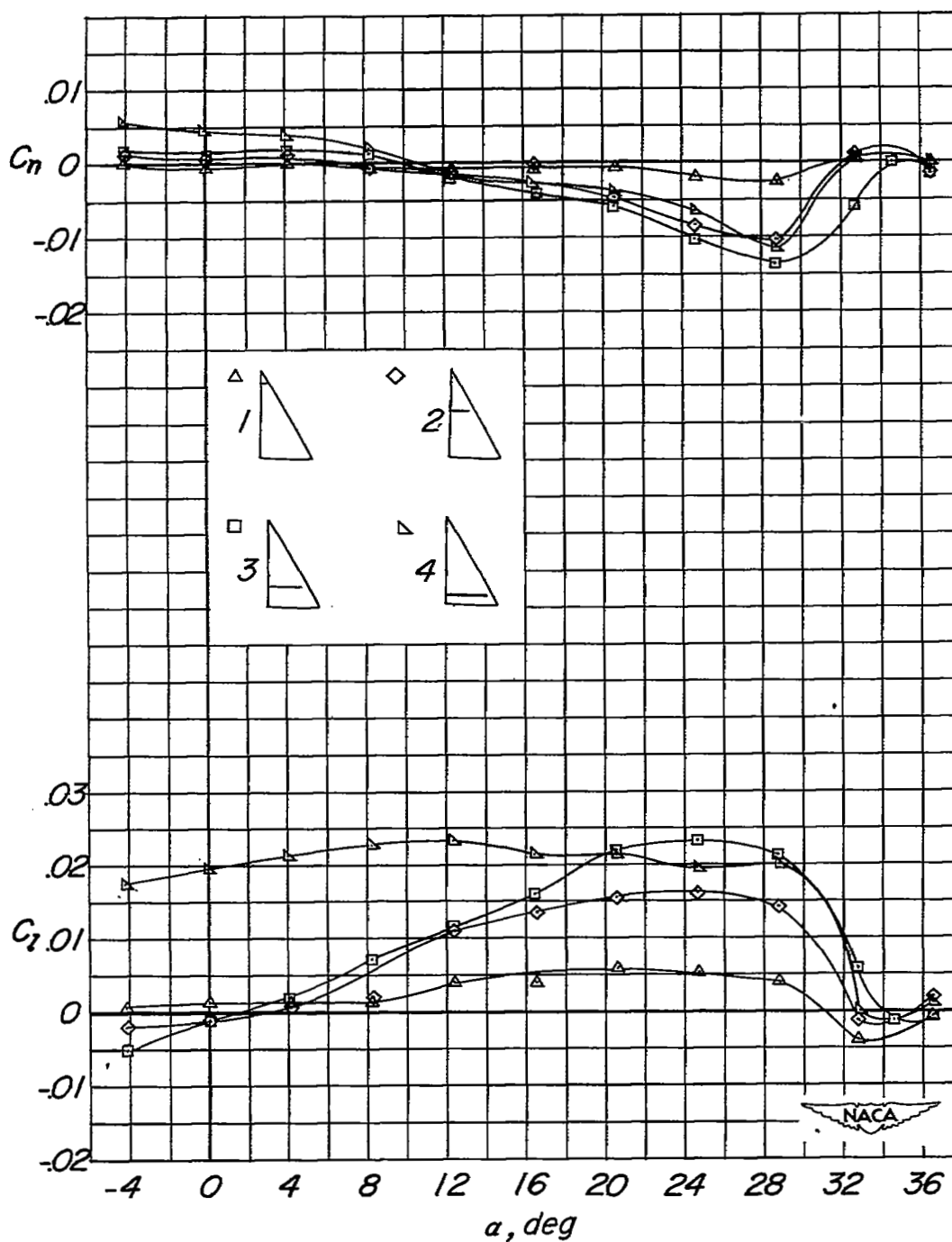
Figure 5.- The variation of rolling-moment and yawing-moment coefficients with angle of attack for spoilers of -0.072c̄ projection and various chordwise positions and spanwise lengths on a thin 60° delta wing. (Spoilers 1 to 4.)
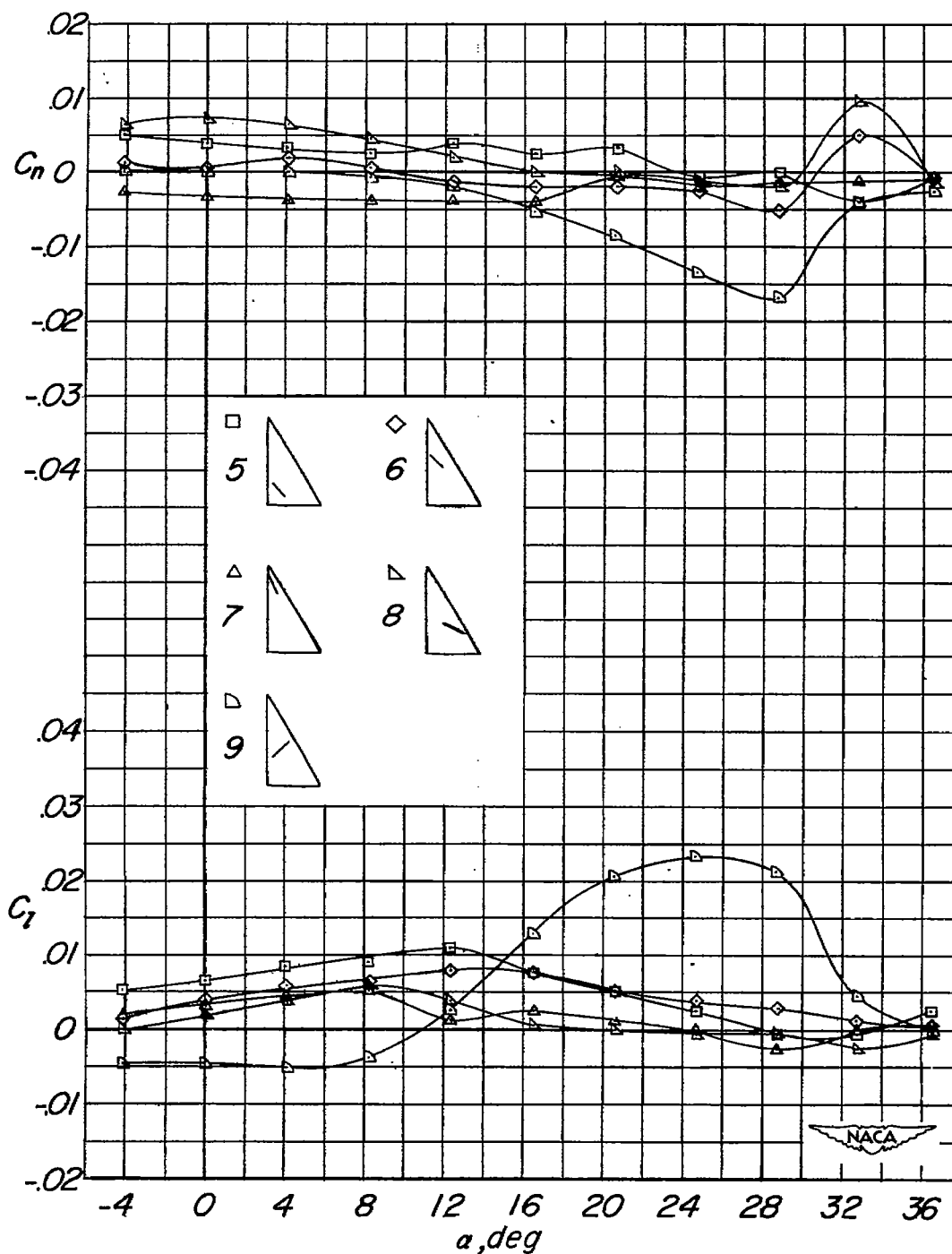
Figure 6.- The variation of rolling-moment and yawing-moment coefficients
with angle of attack for spoilers of -0.072c̄ projection and various
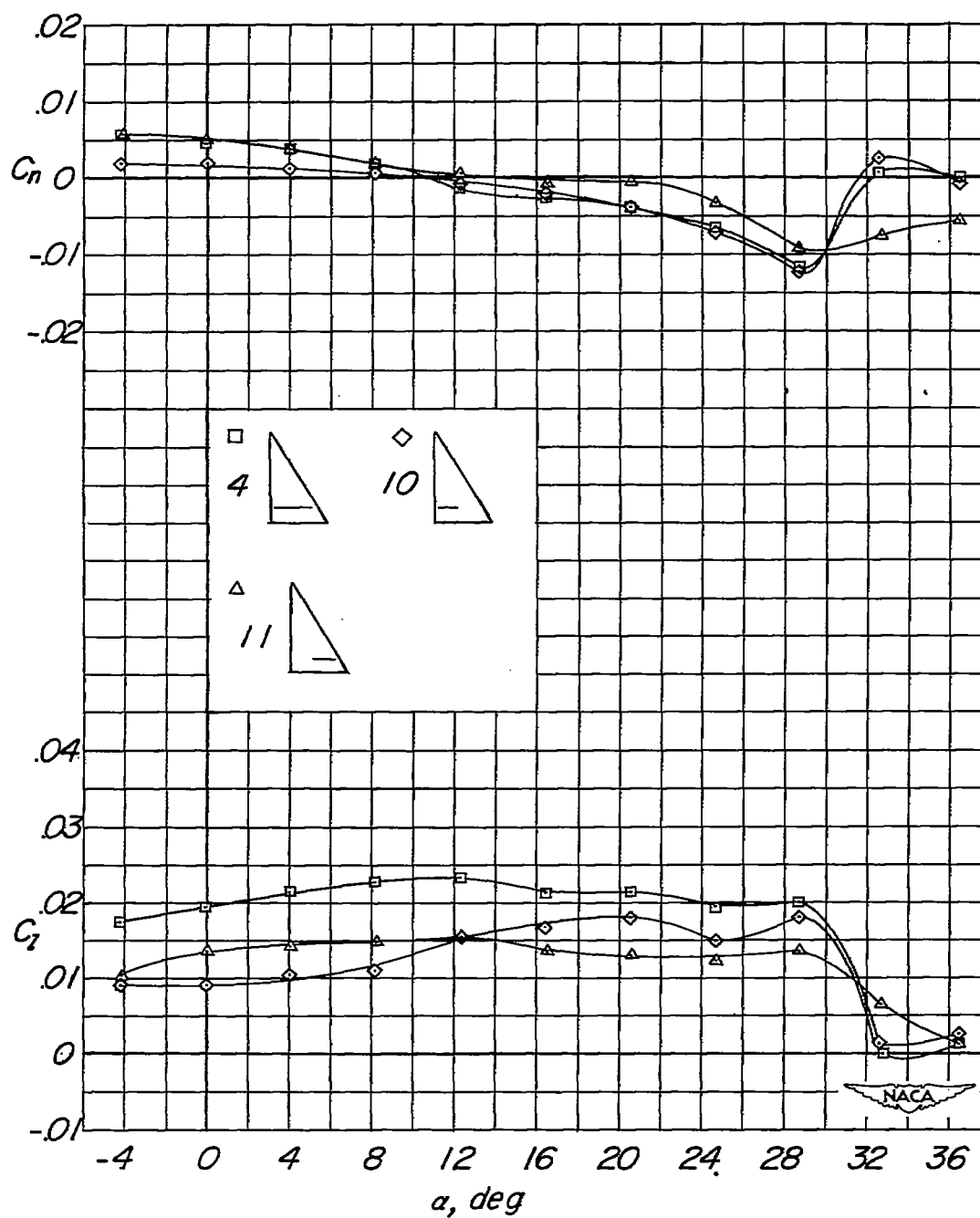angular placements on a thin 60° delta wing. (Spoilers 5 to 9.)

Figure 7.- The variation of rolling-moment and yawing-moment coefficients with angle of attack for spoilers of -0.072$\bar{c}$ projection and various spanwise positions located at the 0.87c_r station on a thin 60° delta wing. (Spoilers 4, 10, and 11.)
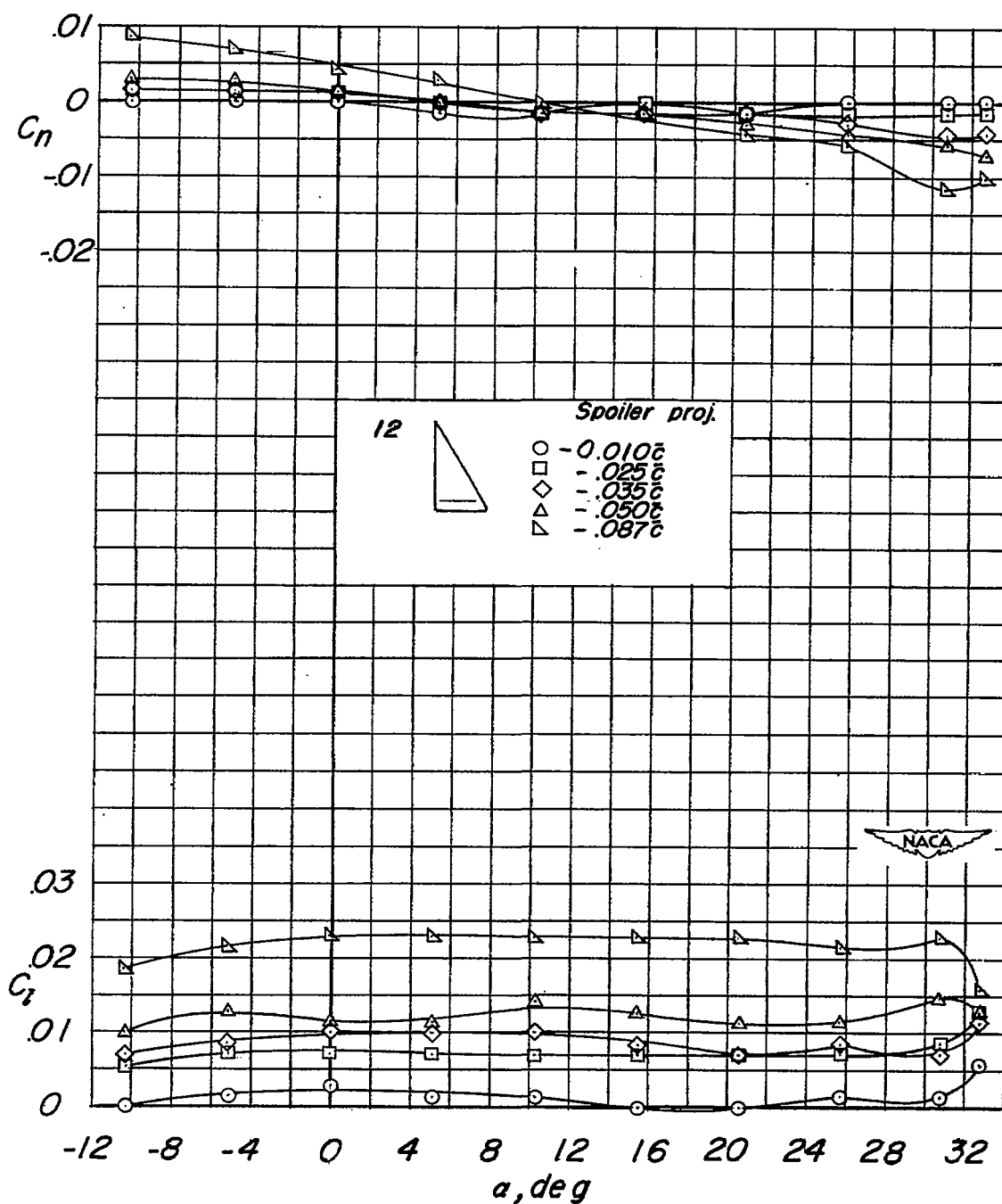
Figure 8.- The variation of rolling-moment and yawing-moment coefficients
with angle of attack for a spoiler located at approximately 0.90c_r on
a thin 60° delta wing and extending from the fuselage to 0.67b/2 with
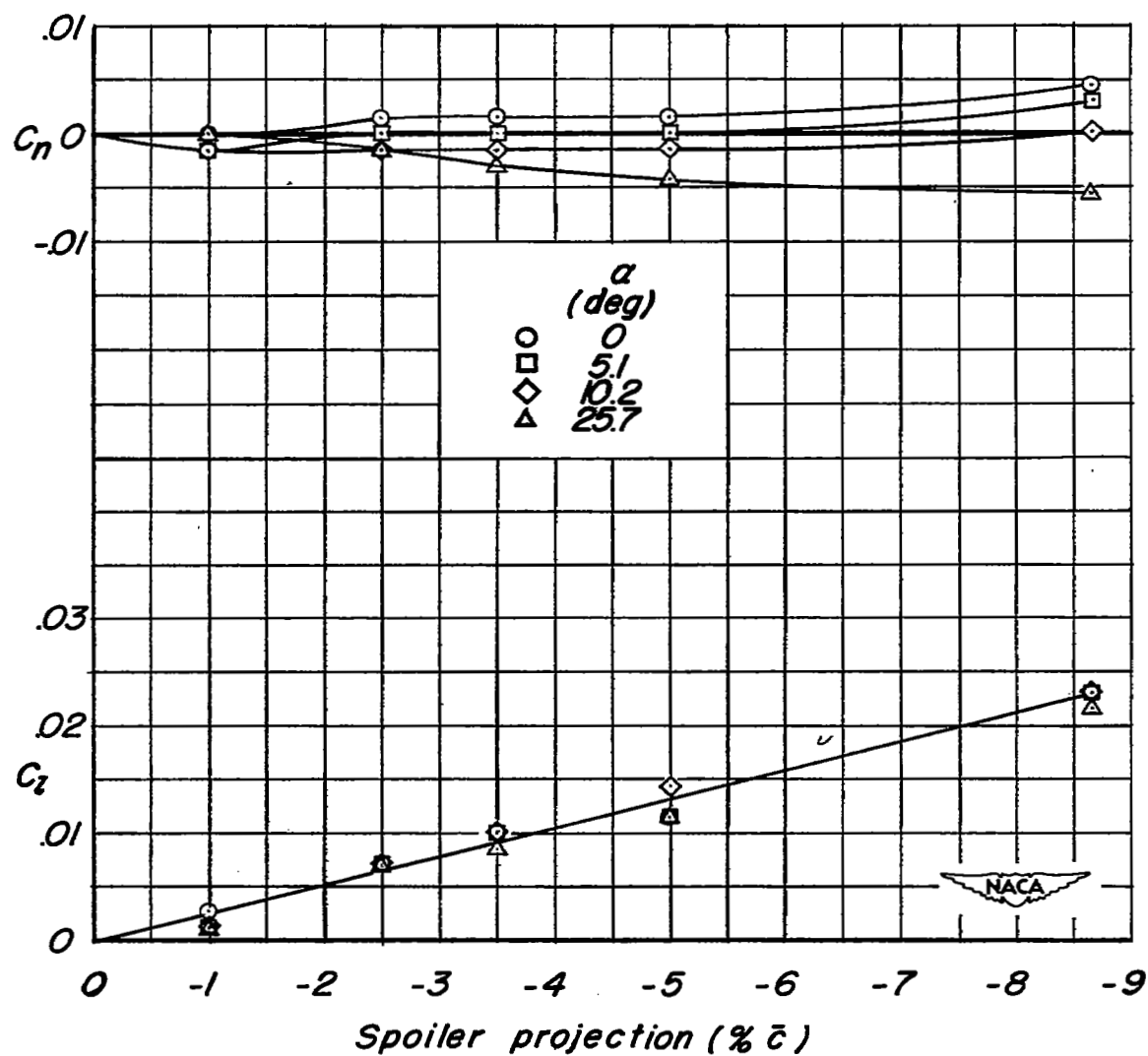projections of -0.010c̄, -0.025c̄, -0.035c̄, -0.050c̄, and -0.087c̄.
(Spoiler 12.)

Figure 9.- The variation of rolling-moment and yawing-moment coefficients with spoiler projection for a spoiler located at the $0.85c_r$ station on a thin $60°$ delta wing and extending from the fuselage to $0.67b/2$. (Spoiler 12.)
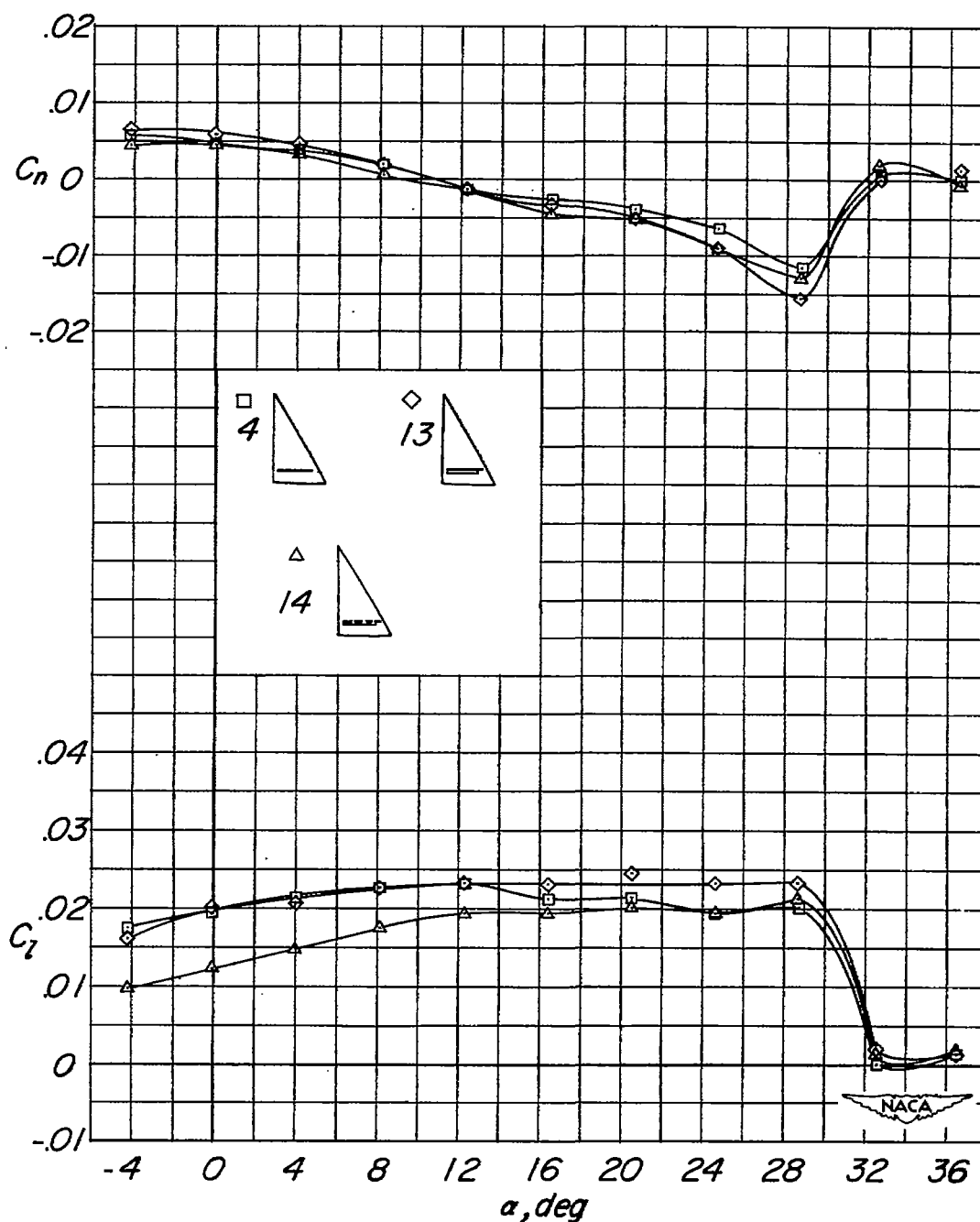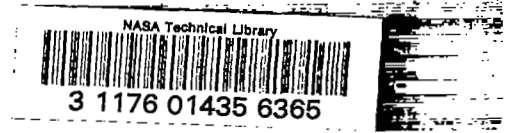
Figure 10.- The variation of rolling-moment and yawing-moment coefficients with angle of attack for solid and perforated spoilers of -0.072$\bar{c}$ projection located at 0.85c_r and 0.90c_r stations on a thin 60° delta wing with and without wing slots.   (Spoilers 4, 13, and 14.)